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JUL 80 R VANSELOW

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) At the Fourth International Summer Institute in Surface Science, twenty one leading scientists presented tutorial review talks on gas-solid and gas-liquid interfaces. Paper topics: "Develop- ment of Kinetic Aspects in Catalysis Research", "Reaction Mechanisms in Catalysis by Metals", "Diffusion in Surface Lay- ers", "Chemisorption-Induced Surface Reconstruction", "Ion Scattering for Surface Structure Determination", "Molecular		

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Beam Epitaxy-Surface and Kinetic Effects", "Determination of Crystallography Habit, and Epitaxial Orientation of Nanometer-Size Particles by TEM", "Computer Simulation and Theory of Interfaces", "Mechanisms of Chemisorption and Oxidation", "Abinitio Cluster Model Studies of Chemisorption: Utility and Limitations", "Electronic Structure of Semiconductor and Transition Metal Surfaces", "Determination of Atomic and Electronic Structures of Surfaces Using Synchrotron Radiation in the XUV Region", "Surface Vibrations - EELS", "Surface Enhanced Raman Spectroscopy", "Extended X-Ray Absorption Fine Structure Studies on Surfaces", "Application of IR-Spectroscopy to Chemisorption and Catalysis on Metals", "Surface Structural Sensitivity of Angle Resolved UPS and EELS", "Recent Progress in SIMS", "Plasma Etching of Surfaces", "Structure and Properties of Crystal-Melt Interfaces", and "Molecular and Atomic Beam Scattering from Surfaces".

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(1) FOURTH INTERNATIONAL SUMMER INSTITUTE IN SURFACE SCIENCE (4th),

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The academic goals of ISISS were outlined in the editorial comments of "Surface Science: Recent Progress and Perspectives (ISISS 1975)":

"The favorable acceptance of ISISS was gratifying, but did not exactly come as a surprise. During the recent decade, advanced ultrahigh vacuum technology has made the achievement of pressures  $< 10^{-10}$  Torr a routine operation so that surfaces, once freed from impurities, can be kept clean over a sufficient length of time and adsorbates then can be admitted at well-dosed amounts. Techniques for surface analysis were more and more refined; with the atom probe we are now able to analyze even single surface atoms or chemical complexes. Progress in the theory of the solid state subsequently allowed some fruitful dealing with the theoretical aspects of solid surfaces. All these developments combined with the demand for data by vital branches of our modern technology, caused an increasing flood of publications especially in the field of gas-solid interfaces. It became hard to catch up with the literature in one's own narrow area and it appeared nearly impossible to keep track of the developments in neighboring fields. As in other fast developing parts of the natural sciences, one consequently observes some isolationism and the appearance of communication problems. It is quite clear that such a tendency, where one no longer learns from progress or setbacks in neighboring areas, would be very much to our disadvantage. To counteract this tendency, ISISS was organized. Leading experts from various subdivisions of surface science - we chose to restrict the topics to gas-solid interfaces - presented tutorial review talks in which recent progress was summarized and future trends were pointed out."

In order to keep ISISS 1979 at a level of highest quality all former ISISS speakers were invited to suggest names of suitable lecturers. To avoid duplication, none of the lecturers of the 1977 Summer Institute were invited to present a paper. The final list showed twenty-one internationally known experts in the field of gas-solid (liquid-solid) interfaces. The speakers came from France, Germany, Sweden, the United Kingdom, and from the U.S.A.

The following list shows their names, their affiliations, topics, and short summaries of the papers presented.

Farid F. Abraham, IBM, San Jose, California

Computer Simulation and Theory of Interfaces

We describe the Monte Carlo method for simulating, on the computer, the thermodynamics and structure of model systems. The utility of this theoretical tool for studying surface physics problems is demonstrated by briefly reviewing selected Monte Carlo simulations of microclusters composed of simple atoms, the planar liquid surface, the solid-liquid interface and the crystal-glass interface.

Stig Andersson, Chalmers University of Technology, Göteborg, Sweden

Surface Vibrations - EELS

High-resolution electron energy loss spectroscopy (EELS) has become a useful probe of the vibrational states of atoms and molecules adsorbed on single crystal surfaces. The spectra yield frequencies of characteristic modes over a wide frequency range which provide a relatively straightforward and detailed insight in the structure of the adsorbed species and in certain cases also the adsorption site. In order to interpret the intensities of the vibrational loss lines one must know the interaction mechanism between the incident electron and the vibrational mode. The intensity data provides information related to the concentration and the orientation of the adsorbate and to the electronic properties of the adsorbate-substrate bond.

Paul S. Bagus, IBM, San Jose, California

Ab Initio Cluster Model Studies of Chemisorption: Utility and Limitations

This paper will focus on the application of cluster model studies to various properties of chemisorbed systems. In the cluster model approach a small number of atoms representing the surface plus a chemisorbed atom or molecule are considered as a quasi-molecule. Wave functions are determined for this quasi-molecule and its properties interpreted in terms of processes on an extended real surface. The paper will be divided into three major sections.

I. Determination of the Equilibrium Properties of Chemisorbed Atoms.

The principle properties of interest are the equilibrium bond

distance from the surface, the vibrational energies of the adatom, and the binding energy for adsorption. These properties may be, and usually are, computed for different sites on the surface. Thus, bonding mechanisms and properties for different sites may be compared. The interaction of F and Cl atoms with a Si surface will be discussed in detail. It will be shown that F atoms can penetrate into the Si lattice by going over a relatively small barrier. By contrast, the barrier for Cl penetration is very high. These results are consistent with the observed different reactivity of F and Cl with Si. They provide a model for understanding reactions relevant in plasma etching.

## II. Analysis of Photoemission Spectra of Chemisorbed Molecules.

The shifts between the photoemission spectra of free and chemisorbed molecules can provide information related to the nature of the chemisorption bond. Simple cluster models will be applied to both the core and valence level spectra. For the valence levels, in particular, binding energy shifts can be used to demonstrate similarities and differences between the bonding of different adsorbed molecules on transition metal surfaces. Cluster studies of the core levels have made possible a better understanding of the anomalously large satellite structure observed in many cases. The relationship between bonding (and bond distance) and the relative intensities of fully screened and partially screened core level satellites will be described.

## III. Limitations of the Cluster Model Approach.

The limitations to be discussed here are those which appear, to the author, to be inherent in the use of finite clusters rather than in any particular implementation of the model. The limitations relate to the ability to describe properties principally related to the substrate.

Gert Ehrlich, University of Illinois at Urbana-Champaign

### Diffusion in Surface Layers

Surface diffusion has only recently become a topic of wide interest. This neglect is surprising, as diffusion plays an important role in surface processes. It has long been appreciated that the movement of reaction intermediates over catalysts particles is one of the significant steps in heterogeneous catalysis; this is well-illustrated in Professor Ertl's review. Studies of sur-

face diffusion can also provide insights into the nature of the bonding at an interface. Finally, in crystal and thin film growth as well as in sintering, material transport by self-diffusion over the surface is all-important. That despite all this, surface diffusion has not received more attention must in large measure be ascribed to experimental difficulties inherent in such studies. Only recent developments in analytical techniques have made it possible to carry out measurements of surface diffusion with confidence and relative ease.

In this review the emphasis is primarily upon diffusion in chemisorbed layers. Migration of both electronegative gases and of metal atoms will be surveyed, with the latter serving as an example of the detailed insights that can now be achieved. Surface self-diffusion will be neglected, however, as it has been discussed at one of the previous Summer Institutes. Although the atomic processes in diffusion on crystals are of primary interest here, the central role of techniques will be strongly reflected in the material covered and in the order of presentation.

Peter Eisenberger, Bell Laboratories, Murray Hill, New Jersey

#### Extended X-Ray Absorption Fine Structure Studies on Surfaces

As early as the 1930's, it had been observed that the absorption cross-section in the x-ray regime had a complex structure as a function of energy extending as far as 1000 electron volts above an absorption threshold. These measurements were made by using a low-power conventional x-ray tube, a dispersive Bragg spectrometer, and film as a detector. After some correct and incorrect speculation concerning the origin of this extended x-ray absorption fine structure (EXAFS), the field remained essentially dormant through the 1950's. In the late 1960's the measurements were revived, this time using modern counting and automation techniques. The previous interpretation of the structure as arising from the backscattering of the ejected photoelectron from the atoms near the absorbing site was strongly supported. The idea that this phenomenon might be used as local structural probe was born. However, even with the experimental advances the measurements were difficult and time-consuming because of the low power of the x-ray source. This limited the application of the technique to highly concentrated systems and also inhibited the systematic study of the phenomenon that was necessary to turn the semiquantitative interpretations into quantitative evaluations.

In 1972 the bremsstrahlung radiation produced by a conventional x-ray tube was replaced in the experiments by synchrotron radiation produced by high-energy storage rings. The increase in flux of approximately  $10^5$  to  $10^6$  provided by the Stanford storage ring SPEAR signaled the beginning of a virtual revolution in the quantitative understanding of EXAFS. In the last 3 years EXAFS has been successfully applied to determining the structural arrangement of as few as  $10^{13}$  atoms on a single-crystal surface and of complex, dilute,



and disordered systems that were previously inaccessible. These studies have spanned the scientific disciplines of biology, chemistry, and solid-state and surface science. In this article we summarized the current quantitative understanding of EXAFS and describe how the measurements are made. We then give some representative examples of the initial applications of the technique to the study of structural problems in surface science.

Gerhard Ertl, Universität München, Germany

#### Reaction Mechanisms in Catalysis by Metals

The rate of a heterogeneously catalyzed reaction will be determined by the nature, concentrations as well as energetic and dynamic properties of the species present on the surface, whereby the structure of the surface itself is an additional parameter. Studies with well-defined single crystal surfaces by means of various surface spectroscopic techniques may serve to elucidate the microscopic steps involved as is illustrated by reviewing two reactions, namely the oxidation of carbon monoxide on Pd and the synthesis of ammonia on Fe catalysts.

Peder J. Estrup, Brown University

#### Chemisorption-Induced Surface Reconstruction

##### 1. Introduction: Adsorption on an Unperturbed Substrate.

Two-dimensional (2D) order due to adsorbate-adsorbate and adsorbate-substrate interactions. Phase diagrams for 2D-gas and lattice-gas models. Examples from physisorption and chemisorption. Comparison with the W{100}/H and Mo{100}/H phase diagrams.

##### 2. Reconstruction of W{100} and Mo{100}

Direct evidence for lattice distortions: LEED data, ion scattering measurements, and electron energy loss spectra. Reconstruction of the clean substrates. Superlattices induced by chemisorbed hydrogen. Correlation with surface electronic properties. Speculations concerning the mechanism of the structural changes.

##### 3. Concluding Remarks

Possible importance of reconstruction in chemisorption phenomena.

L. C. Feldman, Bell Laboratories, Murray Hill, New Jersey

Ion Scattering for Surface Structure Determination

In the last few years a number of groups around the world have been using energetic ion beam scattering from solids as a surface structure tool. These studies have been with energetic particles of greater than 0.1 MeV where scattering cross-sections and the flux distribution of the beam in the solid are well-understood. Low energy ion scattering,  $\sim 1$  KeV, which is very surface sensitive, continues as an important structural probe. However, the physics of the atomic collisions and the method of extraction of information are sufficiently different in these two regimes for each to obtain an individual character.

In this paper we discuss the use of high energy ion beams as a surface structure probe. The second section is a brief review of MeV ion scattering in solids (non-single crystal). The third section considers the special flux distribution of the beam that occurs in an aligned single crystal and explains the origin of the sensitivity to surface structure. In the fourth section we describe a number of recent examples of surface structure investigations using high energy scattering and finally discuss, in more detail, the comparison of this surface probe to low energy scattering and other structural probes.

Currently, high energy ion scattering is at an important stage of development. It is still being calibrated as a technique and, simultaneously, attacking a number of important surface physics problems.

C. T. Foxon, Philips Research Laboratories, Redhill, United Kingdom

Molecular Beam Epitaxy-Surface and Kinetic Effects

A detailed understanding of the mechanisms of growth by molecular beam epitaxy can be obtained from modulated molecular beam measurements combined with diffraction studies. At present the mechanisms controlling the growth of binary compounds are reasonably well-understood but the growth of alloy films with both mixed gp. III and gp. IV elements has been studied in much less detail. In particular the factors controlling the relative incorporation rates of gp. V elements remain to be determined. Some of the kinetic problems associated with dopant incorporation are known but a number of obvious n type dopants such as S, Se and Te have been rejected on the basis of insufficient data and should be studied in more detail. Whether MBE will become a widely used technique for thin film preparation is still uncertain but there

is no doubt that it provides the surface scientist with an excellent means of preparing well-characterized surfaces in situ free from the constraints hitherto imposed by working on cleaved or argon ion bombarded surfaces.

Daniel R. Frankl, Pennsylvania State University

### Molecular and Atomic Beam Scattering from Surfaces

It has become commonplace to remark that the field of atomic and molecular beam scattering from surfaces has been growing at a rapid pace, and that frequent reviews are amply justified by the rate of progress. A few of the most recent reviews are those by Cole and Frankl, emphasizing the quantum regime in both its experimental and its theoretical aspects, by Goodman, dealing mainly with theory, and by Madix and Benziger on reactive scattering. More general surveys were given by Somorjai and Brumbach at the first ISISS and by Ceyer and Somorjai. All of these papers, of course, contain references to the many earlier reviews. In the present paper, we shall attempt to achieve a broad coverage of the field, with emphasis on only the most recent of developments.

#### A. Types of Information

The main reason for the growing interest in atom and molecule scattering from surfaces lies in the variety of types of information it promises. These include:

1. Interaction potentials. This is probably the most highly developed aspect of the field, and is exploited by studies of elastic scattering in the quantum regime of low-mass, low-energy scattering. The data are of basic importance to physisorption phenomena, and thus possibly also to chemisorption, gas-solid chemical reactions, and heterogeneous catalysis.
2. Surface crystallography. Atom diffraction will some day stand as an equal partner with LEED in the elucidation of surface structure. At present, however, this aspect of the field is barely out of the pre-natal stage. The reason for the potential importance of atom diffraction lies in the virtually complete lack of penetration of low-energy atomic beams into crystals. In other words, the atomic beam is much more surface-sensitive than the electron beam. Thus the problems of interpretation of LEED intensities arising from interplanar scattering will not be present.
3. Low-energy excitations. Since molecular beams have kinetic energies in the thermal range (i.e., milli-electron-volts), they are ideally suited for probing non-electronic excitations such as the surface phonons of the solid. This aspect, too, is only in the early stages of its development but is being

actively pursued in several laboratories. Experimentally, the difficult study of inelastic scattering is involved.

4. Reactive scattering. This is a highly varied and, from the practical point of view, highly important area of investigation. The phase-space dissection inherent in the molecular beam technique offers the opportunity for the unravelling of complex reactive and catalytic mechanisms.
5. Energy and momentum exchange. Since these processes are readily measured by beam techniques, this area has possible applications to aerodynamics, spacecraft design, plasma reactor vessels, and other gas-solid interaction technology.

William A. Goddard, III, California Institute of Technology

#### Mechanisms of Chemisorption and Oxidation

First principles calculations using Hartree-Fock (HF) and generalized valence bond (GVB) wavefunctions are reported for the bonding of atomic N, Cl, Na, O, and S on high symmetry sites of the Ni{100} face using an Ni<sub>20</sub> cluster as a model. All of the adsorbates are found to prefer the fourfold site, with bond energies ( $D_e$ ) of 3.04 (H), 3.9 (Cl), 1.3 (Na), 3.63 (O), and 4.34 (S) eV. Bond distances are 0.30 (H), 1.38 (Cl), 2.7 (Na), 0.88 (O), and 1.24 (S) Å above the surface, which are (except for Na) in excellent agreement with available experimental data. Vibrational frequencies of 73 (H), 17 (Cl), 30 (Na), 46 (O), and 37 (S) meV are found for these adsorbates. Decreasing site coordination is found to increase uniformly vibrational frequencies, while decreasing bond distances and bond energies. For Ni<sub>20</sub> and Ni<sub>28</sub> chemisorption of H at sites corresponding to {111} and {110} surfaces is also discussed.

The data are analyzed through the introduction of the concepts of site acidity and basicity, and it is found that site basicity increases with increasing coordination. This trend is responsible for the observed preference of each adsorbate for high coordinate sites, and it is expected that donor adsorbates (such as CO) would show a reverse trend. The data for Na are found to be in poor agreement with analogous bulk data, confirming a previous prediction that small particles lead to much weaker chemisorptive bonds for highly electropositive species than do bulk surfaces.

D. R. Hamann, Bell Laboratories, Murray Hill, New Jersey

Electronic Structure of Semiconductor and Transition Metal Surfaces

- I. General aims of electronic structure studies
- II. Methodologies for extended surfaces
  - A. Empirical LCAO
    - 1. Slab
    - 2. Green's function
  - B. Self-consistent LCAO
  - C. Plane wave pseudopotential
  - D. Mixed basis pseudopotential
  - E. Transfer matrix pseudopotential
  - F. Linear APW
- III. Semiconductor studies
  - A. Clean surfaces
  - B. Reconstruction
  - C. Chemisorption
  - D. Interfaces
- IV. Transition metal surfaces
  - A. Clean surfaces
  - B. Chemisorption
- V. Summary and Conclusions

Klaus Heinemann, Stanford University

Determination of Crystallography, Habit, and Epitaxial Orientation of Nanometer-Size Particles by TEM

The habit faces of various single crystal vapor deposited metal particles in the 5-15 nm size range were determined by a combination of weak - beam dark field (WBDF) transmission electron microscopy (TEM), selected-zone dark field (SZDF) microscopy, and multibeam computer calculations of image intensities. Particles exhibiting square and rectangular shapes in bright field TEM were often found to be truncated pyramids with {001} base and top surfaces and {111} faces. Sometimes {001} based cubes with {001} faces could be identified. Single crystalline pentagonal particles were found frequently and determined to have {001} base and top surfaces, as well as three {111} and two {011} side faces. Particles with triangular bright field profile had a {111} base and three {001} faces. Gold crystallites growing on KCl substrates were found, under certain conditions during the coalescence stage, to form large, irregularly shaped, very flat islands with {001} top surfaces.

Boyan Mutaftschiev, Universite Aix-Marseille, France

### Structure and Properties of Crystal-Melt Interfaces

After a short recall of some definition equations regarding the energetic parameters of the interface between two condensed phases, the authors discuss the different expected cases of surface melting and their relation to the thermodynamic properties of the crystal-melt interface.

The two next sections are devoted to a review of earlier concepts for the crystal-melt interface, namely the lattice-like model and the models assuming unchanged liquid structure up to the interface.

The next part gives results issued from structural models for the crystal-melt interface of monoatomic solids. The main points are: structure and density of the first liquid layers; potential energy and configurational entropy calculations for interfaces represented by a singular (0001) face of an h.c.p. solid; estimations of the same parameters for a non-singular (11 $\bar{2}$ 4) face; Wulff-plot and growth mechanism; Monte-Carlo relaxation of the structural models; mobility in the adjacent liquid layers.

The discussion contains a comparison with the Monte-Carlo experiments of Abraham et al on the crystal-melt interface (001)-face of an f.c.c. crystal.

Finally are exposed some experimental results on morphology and energetics of the crystal-melt interface.

J. Pritchard, Queen Mary College, London, United Kingdom

### Application of IR-Spectroscopy to Chemisorption and Catalysis on Metals

Transmission infrared experiments with supported metals will be briefly reviewed in order to illustrate the information that infrared spectra can provide about surface species. They also serve to demonstrate the applicability of infrared spectroscopy to the study of practical metallic catalysts, even under reaction conditions.

The heterogeneity of supported catalyst surfaces raises problems for the interpretation of spectra. Coupled with the limited wavelength ranges over which support materials are trans-

parent, this has led to the development of reflection methods that can be applied to single crystal surfaces in conjunction with LEED, AES, etc. The physical basis of infrared reflection-absorption and ellipsometric spectroscopy will be outlined, together with the experimental methods that have been employed to achieve adequate sensitivity in practice.

Spectra of species adsorbed at well-defined single crystal surfaces can help in the analysis of transmission spectra from supported catalysts, as will be illustrated by spectra of CO on copper and palladium.

Particularly detailed coverage dependencies of CO spectra have been recorded on a number of single crystals, and the spectra of mixed isotopes have been used to distinguish frequency shifts caused by oscillator interactions from those caused by coverage dependent changes in the surface bond. Such studies require the higher resolution available in infrared spectra in comparison with electron energy loss spectroscopy.

Reflection infrared spectra have already been obtained at relatively high pressures, and the talk will conclude with a consideration of the prospects for in situ studies of catalytic reactions on single crystals.

Georg-Maria Schwab, Universität München, Germany

#### Development of Kinetic Aspects in Catalysis Research

Early in this century BODENSTEIN first measured the kinetics of some simple heterogeneous catalytic gas reactions. His interpretations were based on the assumption of multilayer adsorption and rate determining diffusion towards the catalysis surface.

Langmuir discovered the chemisorption in unimolecular layers and the displacement in binary adsorption. HINSHELWOOD applied these points to the kinetics of many catalytic reactions. To his Langmuir-Hinshelwood mechanism ELEY and Rideal added the Eley-Rideal mechanism.

In the following years numerous theoretical viewpoints were investigated experimentally by kinetic observations. The author contributed to this trend during fifty years by studying the question of active centers and mainly electron transfers in simple and mixed catalysts.

The balance of kinetic and surface-physical research is considered.

David A. Shirley, University of California-Berkeley

Determination of Atomic and Electronic Structures of Surfaces  
Using Synchrotron Radiation in the XUV Region

The present status of photoelectron spectroscopy in the 50-500 eV range is discussed in relation to its application to surface science. Instrumentation aspects of synchrotron radiation sources are reviewed. The direct transition model is shown to be applicable in this range with some limitations. Cooper minima and adsorbate sensitivity enhancement for  $h\nu > 100$  eV are reviewed. A new effect--condensed phase photoelectron asymmetry--is noted. Finally, photoelectron diffraction--another new effect--is described and evaluated.

David S. Y. Tong, University of Wisconsin-Milwaukee

Surface Structural Sensitivity of Angle Resolved UPS and EELS

The surface sensitivity of many ultra-high vacuum spectroscopies comes from the short mean-free-path of either scattered or emitted electrons. The energy of the electrons ranges from a few electron volts to a few hundred electron volts. In this energy range, the wavelength of the electron is about the same order of magnitude as atomic spacings in a solid. Hence, as the electron undergoes strong electron-electron inelastic collisions, which limit its mean-free path, it also diffracts strongly from the arrays of ordered or disordered surface atoms.

To analyze measured data involving either scattered or emitted electrons, one must first understand the effects of electron diffraction. A new technique where electron diffraction effects play an important role is angle-resolved photoemission spectroscopy (ARPS). In this review article, we shall investigate the role and application of electron diffraction in this technique.

Electron diffraction is the primary process involved in low energy electron diffraction (LEED) and by the beginning of 1970, the dynamical theory in terms of a single particle picture with inelastic damping was developed. The major difference in the mathematics of a LEED dynamical theory and that of a conventional band structure calculation is that the former deals with electrons whose kinetic energy is above the vacuum level. Thus, a LEED electron is damped while a Fermi-level band-structure electron is not. The advantage introduced by this damping was cleverly utilized in perturbation methods of LEED that resulted in substantially faster computation procedures.



Extension of the mathematics to treat electron diffraction in angle-resolved photoemission spectroscopy was carried out recently. The extension was mostly done with fast perturbation methods of LEED.

Richard P. Van Duyne, Northwestern University

#### Surface Enhanced Raman Spectroscopy

- I. INTRODUCTION
  - A. Current Status of Electrode Surface Characterization
  - B. Advantages of surface vibrational spectroscopy for the characterization of Electrodes
- II. RAMAN SCATTERING FROM MOLECULES ON ELECTRODE SURFACES
  - A. Sensitivity problems
  - B. Methods for overcoming the sensitivity limitations
- III. THE DISCOVERY OF THE SURFACE ENHANCED RAMAN EFFECT
- IV. SURVEY OF EXPERIMENTAL RESULTS OBTAINED TO DATE
- V. THEORIES FOR THE UNDERSTANDING OF SURFACE ENHANCED RAMAN SPECTROSCOPY
- VI. CONCLUSIONS AND THE PROSPECTS FOR SOLID-UHV STUDIES BY SURFACE ENHANCED RAMAN SPECTROSCOPY

Harold F. Winters, IBM Research Laboratories, San Jose, California

#### Plasma Etching of Surfaces

In this discussion of mechanisms we have considered some results obtained in well-defined (nonplasma) environments and have attempted to relate these results to observations made in plasma systems. Throughout we have used the fluorocarbon etching of Si and Si compounds as an example to illustrate the concepts which have evolved. In conclusion it is appropriate to consider to what extent the Si-F system is unique and to what extent this uniqueness might influence the validity of these concepts as applied to other chemical systems.

Several possibly unique characteristics of the Si-F system come to mind. One is the fact that the most commonly used etch gas ( $\text{CF}_4$ ) does not chemisorb on the etched surface. There are systems in which the etch gas will chemisorb on the surface being etched (e.g.,  $\text{Cl}_2$  etching of Al) and in these cases the availability of active species is no longer limited by the dissociation rate of the etch gas in the plasma. However, it may be that the adsorption rate of atomic chlorine is much faster than that of molecular chlorine whereupon the active species are effectively created by gas phase dissociation of  $\text{Cl}_2$ . It is difficult to

assess the overall consequences of an etch gas which does chemisorb on the etched surface other than to say either the reaction will proceed spontaneously without a discharge (e.g.,  $\text{XeFe}_2$  on Si) or the entire etching process will be radiation assisted (e.g.,  $\text{XeFe}_2$  on  $\text{SiO}_2$ ).

Another possibly unique characteristic of the Si-F system is the spontaneity, at room temperature, of the product formation and product desorption steps in the etching process. Our model for the etching anisotropy indicates that, if either of these two steps is not spontaneous (i.e., does not require radiation), no lateral etching (undercut) will be observed. In other words, vertical walls may be more common in plasma etching than situations showing extensive undercutting. Care must also be taken to avoid confusing thermally induced chemistry with radiation-induced chemistry. In certain etching systems the wafer temperature can be increased substantially above room temperature and reactions which do not occur appreciably at room temperature begin to become important.

Finally, the ability of silicon to abstract fluorine from carbon is a property not shared by all other materials. It is not clear just how important the relative fluorine affinities are in plasma etching but when fluorocarbon etch gases are used there is a constant competition for fluorine between carbon and the etched material and one would expect a material which wins this competition to etch differently than a material which loses.

Since the discussions are an essential part of ISIS, the Session Chairmen play an important role. At ISIS 1979, the following surface scientists served as Chairmen:

Dist. Professor W. Keith Hall	Professor Max G. Lagally
Department of Chemistry and	Materials Science Center
Laboratory for Surface Studies	University of Wisconsin-Madison
University of Wisconsin-Milw.	Madison, Wisconsin
Milwaukee, Wisconsin	

Professor David Lichtman  
Department of Physics and  
Laboratory for Surface Studies  
University of Wisconsin-Milw.  
Milwaukee, Wisconsin

Professor Avram Many  
The Racah Institute of Physics  
The Hebrew Univ. of Jerusalem  
Jerusalem, ISRAEL

Professor J. Heidberg  
Institut für Physik.  
u. Theor. Chemie  
Universität Erlangen

Professor Maurice Webb  
Department of Physics  
University of Wisconsin-Madison  
Madison, Wisconsin

Professor Robert G. Greenler  
Department of Physics and  
Laboratory for Surface Studies  
University of Wisconsin-Milw.  
Milwaukee, Wisconsin

Professor Yehuda Goldstein  
The Racah Institute of Physics  
The Hebrew Univ. of Jerusalem  
Jerusalem, ISRAEL

Dr. James S. Murday  
Office of Naval Research  
Naval Research Laboratory  
Washington, D.C.

One hundred and fifty-one scientists from all parts of the U.S.A., from Canada, France, Germany, Israel, Mexico, Sweden, The Netherlands, and the United Kingdom participated. They came from universities (71%), from industry (21%), as well as government institutions (8%). The educational value of the conference is demonstrated by the fact that about 45% of the participants were Graduate Students and Post-Doctoral Fellows. The registration fee was kept as low as possible.

The following registration fees were requested:

Registration before July 13, 1979:

\$45.00 Regular

\$33.00 Graduate Students and Post-Doctoral Fellows

Registration after July 13, 1979:

\$60.00 Regular

\$43.00 Graduate Students and Post-Doctoral Fellows

Students in the UW System paid a nominal fee.

Besides the scientific program, a number of social programs were arranged. They included a family program, dinner tours, a reception for speakers and participants from foreign countries, and a banquet. Many participants used the opportunity to visit the facilities of the Laboratory for Surface Studies at UWM. In connection with the Summer Institute, an exhibition of surface science books was organized.

International scientific societies and journals announced the conference. About 2700 scientists were contacted directly.

As in the case of former ISISS, the papers presented are published in consecutive issues of CRC-Critical Reviews in Solid State and Materials Sciences under the title "Surface Science: Recent Progress and Perspectives (ISISS 1979). As in 1977, the journal publications will be followed by a CRC Monotopic book (one volume, hard-bound).

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Dr. Ralf Vanselow  
Director, ISISS 1979